Technical Requirement Specification

PXIE MEBT and HEBT quadrupoles and dipole correctors

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Revision History

Revision	Date	Section No.	Revision Description
0	02/06/2013	All	Initial release.

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1. Introduction:

The optical design of the PXIE test accelerator [1] requires warm quadrupoles for focusing the 5mA, 2.1 MeV CW H-beam in the Medium Energy Beam Transport (MEBT) [2] and 1mA, 25 MeV nearly-CW H- beam in High Energy Beam Transport (HEBT) [3] as well as dipole correctors for steering the beam. The nomenclature of these elements is identical in both section and should follow Ref. [4]. This document describes the technical specification for the quadrupoles and dipole correctors.

2. Scope and nomenclature:

The PXIE MEBT beam optics scheme assumes beam focusing by two quadrupole doublets and 7 triplets. They are comprised of quadrupoles of two types, referred in this document as types QF and QD. The doublet consists of two QF-type quadrupoles. The triplet has QD-QF-QD structure. Each doublet/ triplet is immediately followed by a pair of dipole correctors, horizontal and vertical (abbreviated as DC in this text). Each of these sets of two/three quadrupoles and the corrector pair is assembled on a separate mounting frame. The total number of elements required for the MEBT is 11 QF + 14 QD + 9DC.

The HEBT uses 4 QF and 4 DC attached on separate mounting frames to provide larger flexibility in configuration.

In addition, a spare doublet and a spare triplet are required: 3 QF + 2 QD + 2DC.
The numbers are summarized in Table 1.

Table 1 PXIE magnet count and nomenclature for the warm quads

Section	Element	Amount	Comment
MEBT			2 doublet and 7 triplet assemblies
	QF	11	
	QD	14	
	DC	9	
	Frame(doublet)	2	
	Frame(triplet)	7	
HEBT			4 separate quads and 4 dipole sets
	QF	4	
	DC	4	
Spare			1 doublet and 1 triplet
	QF	3	
	QD	2	
	DC	2	
	Frame (doublet)	1	
	Frame (triplet)	1	
Total			3 doublet and 8 triplet assemblies; 4 separate QF and 4 separate DC
	QF	18	

	QD	16	
	DC	15	
	Frame (doublet)	3	
	Frame (triplet)	8	

For uniformity of measurements, the quadrupoles for HEBT should be produced, measured, and delivered as doublets.

3. Key Assumptions, Interfaces & Constraints:

1. The quadrupoles and dipole correctors will operate inside the PXIE enclosure, where the nominal air temperature in the enclosure is ~25C.
2. The enclosure will be accessible with the quadrupoles and dipole correctors being on. Covers of the exposed electrical connections should be planned into the design. If the temperature of the exposed elements is expected to exceed 50C, local barriers preventing accidental touching should be foreseen.
3. The nominal size of the vacuum tube in all quadrupoles is 1 ¼" OD (31.75 mm of the outer diameter).
4. The dipole corrector assembly is mounted and removable in a way that allows the adjacent 2 3/4" vacuum flange (~69.85mm OD) to be secured.
5. A Beam Position Monitor (BPM) is mounted in the middle of the doublet and in the downstream portion of triplet between QF and QD. The space outlined in Fig.1 should be left free of winding. Each BPM has 4 connecting cables pointing inside the gap between the quadrupoles up, down, left, and right. Each QF magnet should have threaded holes on the corresponding outside surfaces of the yoke for mounting the cable fixtures. See Fig. 4 for a layout of the triplet package and neighboring components.
6. The space between the upstream QD and QF quadrupole in the triplet should be the same as that left for the BPM to allow for a bellows.
7. The upper parts of all quadrupoles and dipole correctors should be dismountable for vacuum chamber assembly, possible BPM repair, and a possible 120C bake.
8. Cables feeding all elements will come from the overhead trays.
9. Each doublet or triplet is assembled on a mounting frame together with the dipole coil set. At Fermilab, these frames will be positioned on support stands which allow for overall alignment of the doublet/triplet.
10. The height of the beam line above the floor is 1300 mm.

The quadrupoles and dipole correctors will conform to FNAL Engineering [5] and ES&H Standards [6].

4. Requirements:

The quadrupoles and dipole correctors should satisfy the Project X and PXIE MEBT quadrupoles Functional Requirements Specification [4], which are listed and further detailed below.

4.1 Main quadrupole parameters

Minimum tip separation (diameter)	34 mm
Integrated gradient homogeneity	
in the good field region	1%
Region of the good field (diameter)	23 mm
Maximum integrated gradient	1.5 T for Type QF
	0.85 T for Type QD
Suggested magnetic length	10 cm for Type QF
	5 cm for Type QD
Separation between centers of quadrupoles	
in triplets (QD+QF+QD)-	14.5 cm
in doublets (QF+QF)-	17 cm
(corresponds to the distance between iron of	7 cm in both cases)
Maximum current	≤ 10 A
Maximum voltage (preferable)	≤ 30 V

4.2 Dipole correctors

Each dipole corrector set includes two X/Y (horizontal and vertical) dipole correctors.

Integral of the dipole field-	2.1 mT-m
Region of the good field (diameter)-	23 mm
Integrated field homogeneity in the good field region	5%
Minimum clear aperture (diameter)	75 mm
Available space between the yoke of the nearest quadrupole	
and the wall of a vacuum box downstream	75 mm
Deviation of X and Y fields from perpendicular	< 3º
Maximum current	≤ 2 A
Maximum voltage (preferable)	≤ 10 V

4.3 Outside dimensions:

The transverse dimensions of the quadrupoles (excluding mounting frame) should not exceed 400mm X 400mm. Suggested outside dimensions are shown in Fig. 2 and Fig.3.

4.4 Installation and removal:

1. The upper parts of all quadrupoles are dismountable for vacuum chamber assembly, leak check, BPM repairs, and a possible 120C bake. The quadrupole

design must ensure that this dismounting and following re-assembly leaves all magnetic properties, including magnetic axis positions, within specifications.

2. The dipole corrector set is removable without breaking vacuum for assembling/ disassembling neighboring components.
3. Each doublet or triplet is attached to a mounting frame together with the dipole coil set.
    a. The mounting system provides a rigid alignment of the optical elements and allows adjustment of their transverse positions with a resolution of 0.05 mm and the total travel range of 2 mm.
    b. The longitudinal position of each component should be within 1 mm of the desired nominal positions.
    c. Each component should be mounted perpendicular to the longitudinal (Y) axis to within ±1° in both transverse planes.
4. The frames have mounting holes for securing the vacuum chamber. Positions and size of the holes should be agreed upon with Fermilab.
5. The frames have holes mounting them on the support stands. Positions and size of the holes should be agreed upon with Fermilab.
6. Standard removable lifting eyes are included that are sized appropriately for the assembly weight. If the weight of individual magnets exceeds 12 kg lifting eyes should be included on each magnet

4.4 Alignment:

1. Magnetic axes of quadrupoles in triplets/doublets are aligned within ±0.1 mm according to results of magnetic measurements.
2. The magnetic centers should be stable within ±0.1 mm over the full range of quadrupole currents and possible temperature variations.
3. Each quadrupole should be mounted perpendicular to the longitudinal (Z) axis to within ±1° in both transverse planes.
4. Each quadrupole or dipole corrector set has 6 welded Fermilab-supplied survey fiducials (one inch diameter, 0.5 inch depth): two on each side and two on top. They should be mounted on the outside parts of the elements and should be visible for survey.

4.5 Labeling, Numbering and Quality Assurance:

1. The magnet series designation scheme will be specified by the Fermilab.
2. Components and final assemblies will be labeled with unique serial numbers.
3. Production of components will be documented in Fermilab-style travelers that capture the history of all sub-assemblies and final assemblies.

4.6 Tests:

Each quadrupole or dipole corrector must pass the following tests.

1. Hi-pot: coils against the yoke (500 V, leakage current < 5μA)
2. Ring test: each coil (100 V, 100 Hz).
3. If water cooling is included:

    a. Hydrostatic pressure test of solenoid (200 PSI for 30 min – no visible leaks or manometer pressure drop shall be detected).
    b. Water flow test at 60 PSI pressure drop (> 0.8 GPM).
4. Full power test
    a. Record ambient air temperature and environmental conditions (humidity, air circulation or other relevant parameters)
    b. Turn all quadrupoles and dipole correctors to their maximum currents
    c. Record voltages of each quadrupole and dipole corrector
    d. Monitor surface temperature of all coils
    e. When the temperatures are stable, record them

4.6 Magnetic measurements:

Magnetic measurements are performed in the final assembly with the quadrupoles mounted on the frames as doublets and triplets. Integral field strength and harmonic measurements should be made at a radius of 11.5 mm or larger, using either Single Stretched Wire or rotating harmonic coil technique. Harmonic coefficients should be reported at the reference radius of 11.5 mm, up to order n=8 (dipole is n=1).

Magnetic measurements of the doublets and triplets:

1. For each quadrupole powered individually (with dipole correctors off)
    a. Measure position of magnetic center of each quadrupole, at 5 equally-spaced currents from zero to maximum; confirm that the magnetic centers are consistent with each other within 0.1 mm at all currents
    b. Adjust mechanical positions of all quadrupoles to align the magnetic axis positions within 0.1 mm; verify center positions are indeed aligned
    c. Measure integral magnetic field gradient of each quadrupole, at 5 equally-spaced currents from zero to maximum.
    d. Measure integral magnetic field harmonic coefficients, at 5 equally-spaced currents from zero to maximum.
    e. After all magnets in the doublet/triplet have been measured dismount and re-assemble upper parts of all quadrupoles
    f. Verify magnetic center position of each quadrupole is within 0.1 mm of original axis
2. With all quadrupoles in the doublet/triplet powered at the maximum current (with dipole correctors off)
    a. Measure magnetic center position of the quadrupole system.
    b. Measure integral magnetic field gradient of quadrupole system.
    c. Measure integral magnetic field harmonic coefficients.
3. Dipole coils powered individually (with quadrupoles off)
    a. Measure field angle of each dipole, at 11 equally-spaced current values from negative maximum to maximum.
    b. Measure integral dipole field strength, at 11 equally-spaced current values from negative maximum to maximum.
    c. Measure integral harmonic coefficients, at 11 equally-spaced current values from negative maximum to maximum.

4. Dipole coils powered together (with quadrupoles off)
    a. Measure net dipole field angle, at 11 equally-spaced current values from negative maximum to maximum.
    b. Measure integral dipole field strength, at 11 equally-spaced current values from negative maximum to maximum.
    c. Measure integral harmonic coefficients, at 11 equally-spaced current values from negative maximum to maximum

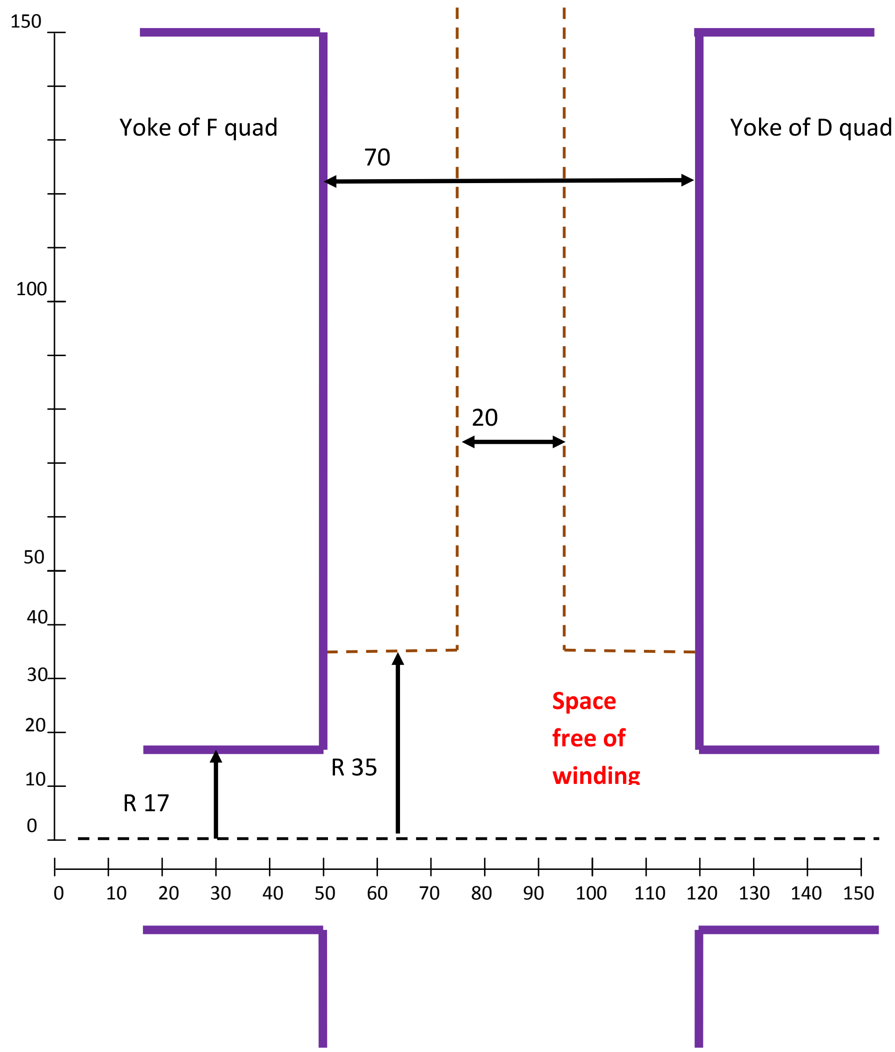

Figure 1: Space between quadrupoles that should be left free of winding for BPMs. All dimensions are in mm. The sketch shows the downstream portion of the triplet; restrictions in the doublets are identical.

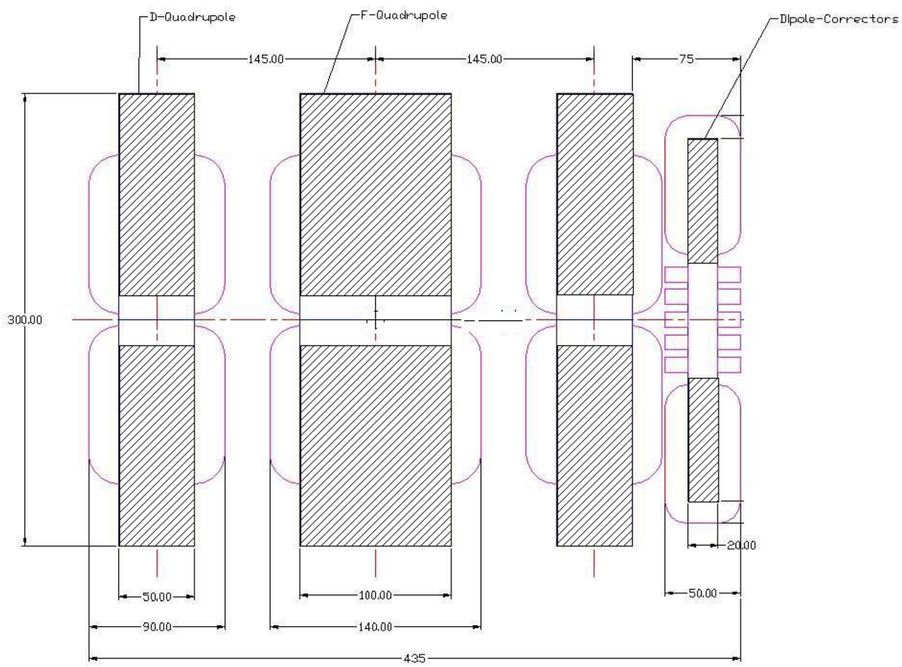

Figure 2. Suggested dimensions, in mm, of the triplet.

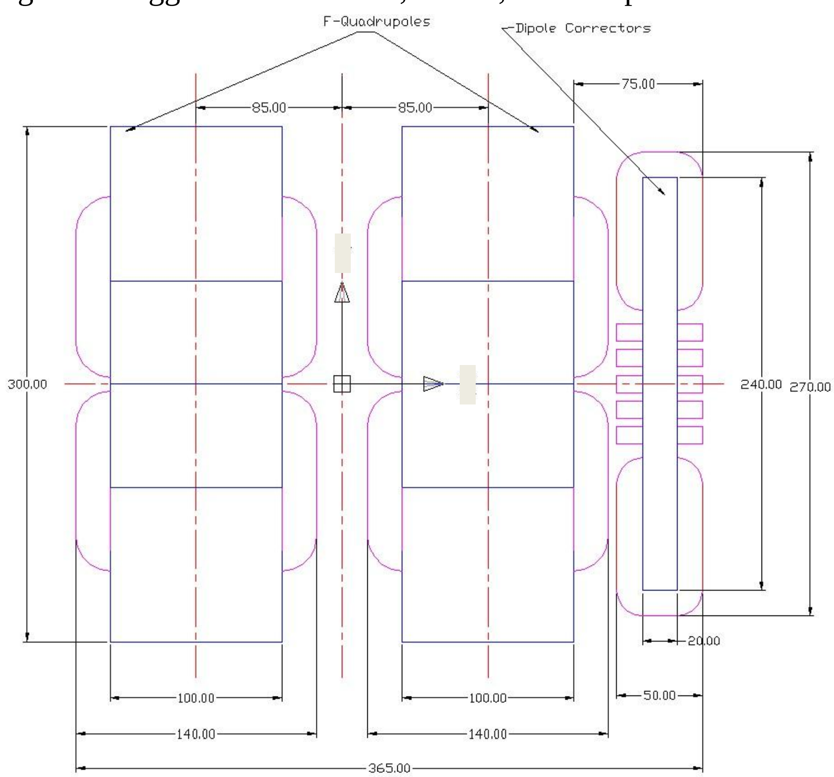

Figure 3. Suggested dimensions, in mm, of the doublet.

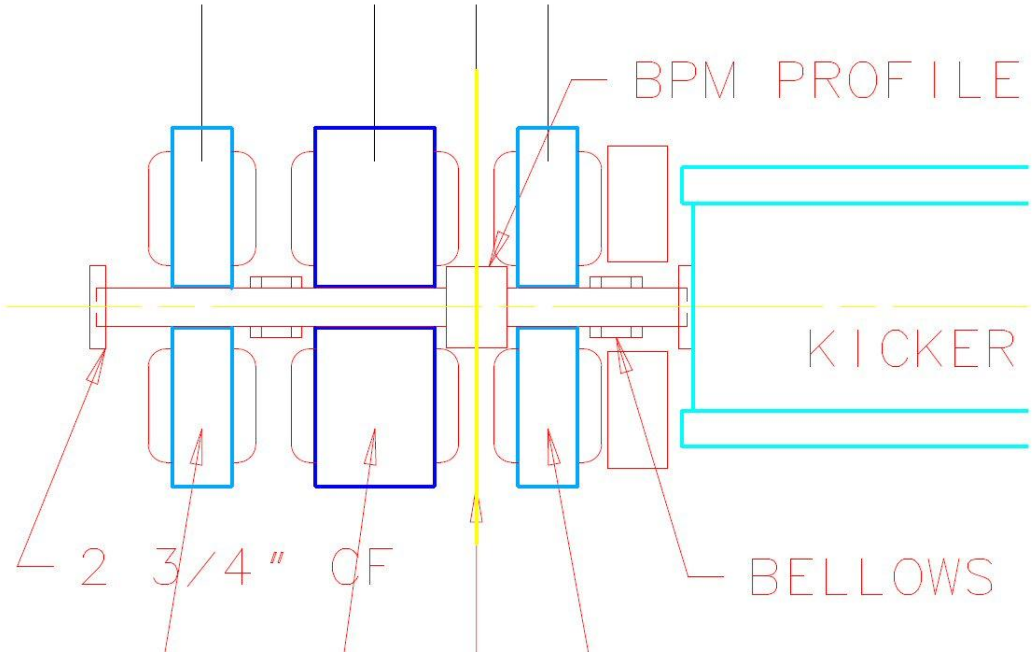

Figure 4. Sketch of Triplet Layout with beam pipe, flanges, and BPM

5. References:

Documents with reference numbers listed are in the Project X DocDB:
http://projectx-docdb.fnal.gov

[1] PXIE Functional Requirements Specification
Document #: Project-X-doc-966

[2] Project X and PXIE MEBT Functional Requirements Specification
Document #: Project-X-doc-938

[3] Project X and PXIE HEBT Functional Requirements Specification
Document #: Project-X-doc-XXX

[4] Project X and PXIE MEBT quadrupoles Functional Requirements Specification
Document #: Project-X-doc-933

[5] Fermilab Engineering Manual
http://www.fnal.gov/directorate/documents/FNAL_Engineering_Manual_REVISED_070810.pdf

[6] Fermilab ES&H Manual
http://www-esh.fnal.gov/pls/default/esh_home_page.page?this_page=15053